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Participation in science in secondary and higher education in Scotland in the second half of the twentieth century

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ABSTRACT

Scientific and mathematical education has expanded in most education systems in the twentieth century, especially in the second half when there emerged the perception among policy-makers that science and technology were essential to a flourishing economy and to individual opportunity. Scotland provides a useful case study of the expansion, for two reasons. One is that it has included natural science in its emerging secondary-school curriculum at an early period by international standards, well before the middle of the century. That inclusion was carried over into the new curricula at the mid-secondary level, which aimed to cater for all students when the public sector of secondary schooling became non-selective after the 1960s. So Scotland is a test case of whether a gradually democratising system of secondary schooling could widen access to science and mathematics, and of whether and how changes at the school level contributed to the expansion of school-leaver entry to science in higher education. The other reason why the Scottish case is potentially revealing is a unique series of surveys of school students that cover the whole of the second half of the century.

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Science; secondary schooling; higher education; social class; sex; comprehensive schooling; Scotland

Introduction

The expansion of secondary schooling and higher education in the twentieth century has included the significant extension of scientific study. From a system provided to a highly selected minority of students, based on the study of languages, history and literature, with, at most, some pure mathematics, the secondary curriculum in most European countries was redefined in the first few decades of the century to be essentially the first steps in a professional education (Kamens and Benavot 1991; Ringer 1979; Perkin 1989). Higher education was reformed in the late-nineteenth and early twentieth century to include scientific and technological studies, many countries emulating Germany in this regard. The debates which led to the massive expansion of higher education from the 1960s onwards then frequently paid attention to the need for a stronger supply of scientists than hitherto.

Scotland made the shift to including science in its secondary schools quite early, in the late-nineteenth century (Paterson 2011). Natural science was accepted as a core part of a liberal curriculum, and was made available as thoroughly in old-established schools as

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in the new schools that were founded by government in the early years of the century to make secondary schooling available to social groups beyond the highest-status elites. Science for girls was also accepted from the beginning of their proper access to secondary schools. Scotland shifted the whole public part of its secondary system to a non-selective basis between the mid-1960s and the late-1970s. Thereafter, it faced the challenge of devising a scientific curriculum that would cater for all levels of ability and interest. Scotland also sought to follow Germany in the creation of technological institutes in the first few decades of the twentieth century. When higher education expanded after the 1960s, it was believed that the Scottish universities and colleges had inherited a strong scientific basis which would thus be able to offer scientific opportunities to the scientifically qualified students who were emerging from the reformed schools at this time.

This paper analyses the expansion of Scottish scientific education in the second half of the twentieth century using a unique series of surveys of school students that stretches from the early 1950s to the late-1990s. It thus uses Scotland as a well-documented case study of whether the study of science and mathematics could be extended to a much wider range of social groups than in the past. The research questions ask to what extent natural science and mathematics became part of the core of secondary schooling, both at mid-secondary stage and later, how participation in scientific and mathematical education was distributed among social groups defined by sex, social class, parental education and their interactions, and how these changes subsequently translated into opportunity to enter scientific and technological programmes in higher education.

Science and society

Three rationales have been offered in the UK for scientific education, each of which may be encapsulated by one word: economy, opportunities and citizenship. It has been believed that science benefits the economy; science provides opportunities to individuals, which then ought to be shared; and scientific knowledge is necessary for being a citizen in a democracy. Although the data which we analyse here relate in a direct sense only to opportunities, the wider context is useful for interpreting the significance of the changes in that respect.

The economy has been the over-riding concern, from the late-nineteenth century onwards (Anderson 1983; Ball 1990, 4–7; Sanderson 1972; Williams 1961). Its importance was intensified with the coming of post-industrial economies from the middle of the twentieth century, which added new perceived needs for skilled staff (Atkinson 1990; Central Advisory Council for Education (England) 1959; Convert 2005; Entwistle and Duckworth 1977; Osborne, Simon, and Collins 2003; Osborne and Dillon 2008). When participation in school science at advanced level seemed to fall back in the 1960s, a committee chaired by the chemist Frederick Dainton suggested that Scotland, with a broader secondary curriculum than England and Wales, was better able to sustain student participation in science (Council for Scientific Policy 1968; Duckworth and Entwistle 1974; McPherson 1969; White 2017). The economic theme became commonplace in policy debates from the 1970s to after the end of the century (Scottish Education Department 1985, 48; National Committee of Inquiry into Higher Education 1997, para. 4.77; Roberts 2002, 33; Scottish Scottish Executive 2001, 1).

The most telling version of the equality-of-opportunity case has been in relation to sex (for example, Jacob et al. 2020; Nunes et al. 2017, 7; Moote et al. 2019, 8–9). One argument has again been economic: women's skills were being lost to science (Roberts 2002, 47), and female students may have been deterred from taking scientific courses by a perception that female opportunities to purse scientific careers were restricted (Moorhouse 2017). The other is about entitlement (Kelly and Weinreich-Haste 1979, 280). The sex differences in the rate of participation in physics (more boys than girls) and biology (the reverse) has long been noted, as has the changing shares of participation in chemistry (Kelly 1987a, 6–7; Buchmann, DiPrete, and McDaniel 2008). The explanations which have been offered have ranged from innate biological differences between men and women, through voluntarily chosen interests, to weaker and stronger forms of social conditioning. In an extensive review of the research, Ceci, Williams, and Barnett (2009, 226) conclude that the changes over time in the sex ratios, as well as simply the growth of female participation in all fields of science, tend to exclude a biological explanation. The evidence for direct social conditioning is weak (246–7), and so the most plausible explanations relate to choice (246), some of it perhaps a weaker form of conditioning, but some of it also because female students who attain highly in mathematics are more likely than similarly attaining male students to attain highly also in language and thus to have more choice of fields to pursue. Similar conclusions have been reached by research throughout the period since the 1960s (for example, Butcher and Pont 1968; Entwistle and Duckworth 1977; Hill, Pettus, and Hedin 1990; Kelly 1987b; Osborne, Simon, and Collins 2003; Roger and Duffield 2000). Such inferences show the value of investigating sex differences over a long period of time, because that is one way of revealing how malleable they might be.

There has also been some attention to socio-economic differences in participation in science (for example, Gardner 1975; Nunes et al. 2017; Moote et al. 2019; Ro, Fernandez, and Alcott 2018). Gorard and See (2009, 98–9) note that there is no clear evidence that would show whether such inequality has explanations that are different from more general socio-economic inequality of progression and attainment.

Although the economic arguments for extending opportunity have probably been the most persuasive politically, there has always also been an argument based on citizenship. Kamens and Benavot (1991, 138) explain that mathematics and science came to embody the essence of the rational citizen. DeBoer (2000) says that this cultural view of science education lost out to the economic rationales after the 1950s. Nevertheless, scientific education has also been able to draw upon the aim of equipping citizens to understand the place of science in society (Ryder 2001, 40; Smith 2010). The equal-opportunities argument, though instrumental in its own way, may also be said to have kept the citizenship idea alive (Kelly and Weinreich-Haste 1979, 281). Successive policy documents have never in fact wholly lost sight of the civic ideas (Scottish Education Department 1947, 19, 1955, 172; Central Advisory Council for Education (England) 1959, para. 77; Council for Scientific Policy 1968, 2).

The culmination of a civic way of thinking about scientific education in Scotland was a fundamental reform in the late-1980s of the curriculum in the middle years of secondary school, leading to a compulsory breadth of study under eight modes, including the mathematical and the scientific. The new courses thus introduced led to new certificates called Standard Grades (Croxford 1994, 1997; Gamoran 1996). The new curriculum was based on the ideas of Hirst (1975), who had argued for the teaching of science to all pupils because it was one fundamental dimension of knowledge. As part of this policy, and as well as retaining courses in mathematics, biology, chemistry and physics, a general science course was introduced at the mid-secondary level. Following the introduction of Standard Grade, a mandatory curriculum framework was set in place in the 1990s, making science compulsory in public-sector schools, which educated 95% of pupils (Croxford 1997). This reform might be interpreted as following the belief that the most effective way of changing the social distribution of scientific opportunities would be by changing the structure of the curriculum, not by, for example, campaigns merely to encourage more girls to take science (Jacob et al. 2020). Scotland thus followed an international tendency in curricular reform whereby an attachment to universalistic principles weakened the socially invidious patterns of subject choice that had been common (Ayalon and Livneh 2013; Charles and Bradley 2002).

This paper investigates participation in mathematics, science and technology by secondary-school students in Scotland between the late-1940s and the end of the century. It asks whether the reforms arising from these debates, and in particular the curricular reform of the 1980s, were followed by any reduction of social differences in rates of participation in science at school and in entry to scientific and technological courses in higher education. We return briefly to the wider questions about the economy and about citizenship at the end.

Methods

Surveys

The analysis uses data from 14 surveys which are referred to by the date at which their members turned 16: 1952, 1960–2, 1968–70, 1970–2, 1974–6, 1976–8, 1978–80, 1980–2, 1984, 1986, 1988, 1990, 1996, and 1998. The 1952 survey was a birth-cohort study (Paterson et al. 2011). The surveys 1960–2 to 1980–2 were leavers' surveys, the range of years for age 16 reflecting the range of ages at which the sample members left school. The surveys from 1984 onwards were cohort surveys, based on a sample of students in the fourth year of secondary school who were then followed up over the subsequent years. Although the surveys were not planned prospectively as a series, the design of each them built upon the earlier parts of this series. So the question wording and sample design were consistent. The purpose was always to gather information on the full range of young people's social background and their achievements and activities in the final years at school. Funding came from a variety of sources, notably the UK Economic and Social Research Council (and its predecessor), Scottish and UK government departments, local authorities, and charities. The surveys were managed by the Scottish Council for Research in Education (1952 and 1960–2), the Centre for Educational Sociology at Edinburgh University (1968–70 to 1990), and ScotCen Social Research (1996 and 1998). The management of the surveys was independent of funders. Full details are provided by Burnhill et al. (1987), Croxford, Iannelli, and Shapira (2007) and Gray, McPherson, and Raffe (1983).

The target samples varied greatly in size (largely depending on the funding that was available in each survey year), as is reflected in the sample sizes shown in Tables 1 and 6.

The surveys included all schools – both schools which were managed by public authorities and schools which were independent of these. Pupil response rates were: 98% for the 1952 survey (Paterson et al. 2011), virtually 100% for the 1960–2 survey (Powell 1973: 22), around 80% for the leavers' surveys from 1968–70 to 1980–2 (McPherson and Neave 1976: 130; McPherson and Willms 1987), and around 65% for the surveys from 1984 onwards (Croxford, Iannelli, and Shapira 2007).

We use these surveys as two kinds of series. For models of the full range of student attainment, we use 1952 and 1974–6 to 1998. The 1974–6 survey covered students with the full range of attainment only in five regions of Scotland, which included around three quarters of all pupils (Gray, McPherson, and Raffe 1983, 16–23); only that part of the survey is included in this first series, used for Table 1 to 5 and Figure 1 to Figure 3. The surveys 1960–2 to 1970–2 surveyed only people who had taken at least one senior-secondary course, and so these are used only for analysis of entry to higher education, for which we restrict the later surveys in the same way. There were too few such students in the 1952 survey (only 112) to allow it to be included in this second series. This series was used for Tables 6 and 7 and Figures 4 and Figure 5.

Measures

We model students' participation and attainment in science at mid-secondary level and in the senior secondary years, and their entry to science and technology in higher education upon leaving school. At school level, the criteria are derived from the various courses and assessments in school-leaving examinations. Throughout this period, there were two main levels of certification available in Scottish secondary schools. One was at mid-secondary level, and was called Lower Grade at the time of 1952 survey, Ordinary Grade for the surveys 1974–6 to 1990, Standard Grade for the surveys 1986–98, and Intermediate 1 and 2 for the 1998 survey. There was some overlap in time between the available awards, as reforms to assessment were implemented over several years, but the policy intention was to maintain consistency of standards at this level (Croxford 1994;

Table 1. Natural science and mathematics at mid-secondary level.

% of sample	Sat any natural science[1]	Passed at least one science[2]	Passed biology	Passed chemistry	Passed physics	Passed general science	Passed mathematics[3]	
Year when respondent was aged 16[1]								*Sample size*
1952	6	5	-	-	-	-	9	1,158
1974–6	32	22	9	15	15	-	36	15,932
1976–8	40	27	12	18	17	-	45	8,631
1978–80	43	28	12	18	16	0.1	44	21,022
1980–2	46	30	14	19	17	0.1	48	6,966
1984	51	33	16	21	19	0.1	50	3,817
1986	62	37	18	22	19	3	52	3,830
1988	69	40	21	23	21	3	53	3,318
1990	79	41	22	25	22	2	42	2,530
1996	94	66	31	35	31	7	55	2,230
1998	94	68	33	36	31	7	56	4,431

Percentages weighted; sample sizes unweighted.
[1] For explanation of which surveys are used here, see Methods section.[2] Not including mathematics.
[3] Mathematics includes arithmetic O grade from 1974–6 to 1990.

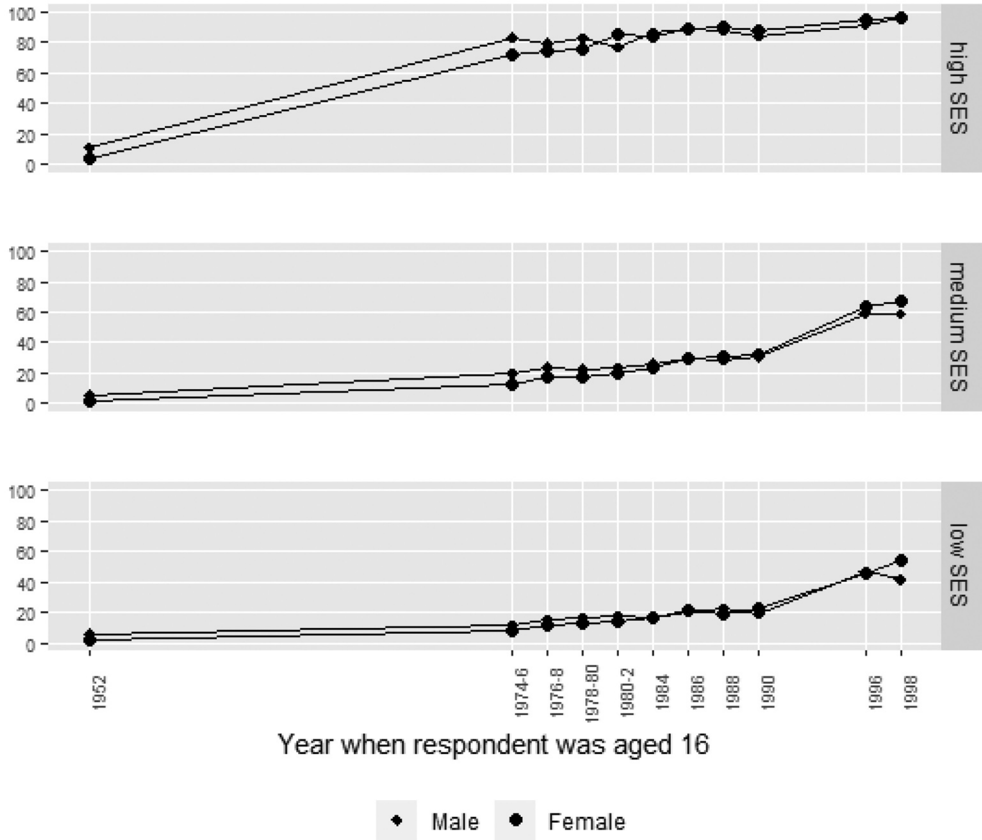

Figure 1. Predicted percentages passing any natural science at mid-secondary level, by sex, socio-economic status, and year. *Source: predicted values from Model 2 in* Table 2.

Gamoran 1996; Gray, McPherson, and Raffe 1983, 52–8). Assessment was by examinations taken at the end of the course, and was by what would usually be called 'grade-related criteria'. That is, the assessment was by means of a norm-referenced scale in which each point of the scale was associated with particular criteria. We simplify the scale to pass and fail, as officially recognised in the regulations governing all these types of assessment. We record at this level taking the assessment in any natural science, passing any such assessment, and passing assessments in mathematics, in biology, in chemistry, in physics, and in general science. Apart from mathematics, these separate subjects were not recorded in the 1952 survey. General science existed as a subject only from 1980, and became important only with the introduction of Standard Grade from 1986. Mathematics included the subject called arithmetic in the Ordinary Grade courses. The courses leading to this mid-secondary certification could be taken in any of the fourth, fifth and sixth years of secondary school corresponding to modal ages approximately 16–18, though they were mostly taken in fourth year at modal age 16.

The second kind of certification was at an advanced level beyond these mid-secondary courses, and was mostly taken in the fifth and sixth year of secondary school (modal ages 17–18). These courses were called Higher Grade throughout, usually abbreviated to

Table 2. Binomial logistic models of natural science at mid-secondary level, by year, sex, class and parental education: Type II chi-squared tests.

		Sat any science[3]	Passed at least one science[3]	Passed biology	Passed chemistry	Passed physics	Passed general science	Passed mathematics[4]
Term in model (: is interative effect)	Degreees of freedom[1]	1	2	3	4	5	6	7
Year	10, 9, 7	5,021**	3,402**	1,206**	400**	266**	64,771**	711**
Sex	1	138**	102**	1,570**	225**	2,794**	11**	0.4
Class[2]	2	1,898**	2,392**	1,121**	2,145**	2,204**	51**	2,446**
Parental education	4	1,838**	2,738**	1,264**	2,645**	2,269**	198**	2,146**
Sex:class	2	15**	9**	3	4	5(*)	12**	5(*)
Sex:parental education	4	43**	44**	20**	10*	35**	206**	32**
Class:parental education	8	37**	56**	49**	64**	59**	22**	33**
Year:sex	10, 9, 7	168**	198**	91**	72**	62**	488**	34**
Year:class	20, 18, 14	50**	40**	33*	72**	32*	1,209**	64**
Year:parental education	40, 36, 28	1,260**	1,120**	135**	151**	133**	7,707**	236**
Sex.year.class	20, 18, 14	22	12	23	9	15	806**	27
Sex.year. parental education	40, 36, 28	224**	217**	38	33	30	2,878**	40

[1] Number of years (as shown in Table 1): 11 for columns 1,2 and 7, 10 for columns 3, 4 and 5; 8 for column 6.
[2] Class is in three groups: I,II; III; IV,V,other.
[3] Not including mathematics.
[4] Mathematics includes arithmetic O grade from 1974–6 to 1990.
The table shows the type-II tests associated with each term.
*Key for statistical significance levels: ** $p < 0.01$; * $0.01 < p < 0.05$; (*) $0.05 < p < 0.10$.*

'Highers' colloquially. Again, the assessment was by means of what were, in effect, grade-related criteria. For most purposes, we simplify the scale to be pass or fail. Thus we use measures which record sitting any natural science, passing any natural science, and passing in mathematics, in biology, in chemistry, and in physics. The Higher Grade courses and certificates were the normal means of access to university and the professions in Scotland. For entry to higher education, using the surveys from 1960–2 onwards, we also derive a measure of general school attainment by combining the number and quality of awards at Higher Grade, not just the number of passes at grades A-C. This measure is defined as:

$$(number\ of\ passes)\ +\ 0.5x(number\ of\ A\ awards)$$

This is analogous to the 'points' system which, towards the end of the century, was used by universities as the main basis for selecting students for entry (Universities and Colleges Admissions Service 2020). We also record, as further explanatory variables, dichotomous indicators of whether the respondent had passed Higher mathematics or Higher science.

For classifying the main subject studied in higher education, we distinguish between science and technology, and between degree-level study and any higher education course (which includes one-year certificates, two-year diplomas, and degrees). The subject classification is based on those used by the UK Higher Education Statistics Agency and its predecessors. The most common courses included in science are physics, chemistry, biological sciences, computing, mathematics and medicine. The most common in technology are the various branches of engineering, building and agriculture. The sample numbers entering these separate disciplines were too small to model each separately.

A variable recording sex is available in all surveys. Around 50% of each sample was female. Social class is the Registrar General social class of the father, grouped for the analysis into I,II; III; IV, V, other. Parental education was recorded in all but the 1960–2 survey as the age at which each parent left full-time education (15 or younger; 16; 17 or older, or unknown). Social class and parental education followed a familiar trend over the half century. For example, the proportion of students who had at least one parent educated to age 17 or older was 4% in 1952, 11% in 1980 and 34% in 1998. The proportion with a father who worked in classes I or II (professional or semi-professional) was 12% in 1952, 21% in 1980 and 30% in 1998. The 1960–2 survey did not have any information on parental education, but, in order to be able to use this variable with the whole series, we imputed the modal value of parental education for each of the six categories of father's class. These modal values were estimated from the 1962 sweep of a Britain-wide cohort study of people born in 1946 (Kuh et al. 2011), using sample members who were resident in Scotland at that sweep and who, in subsequent sweeps, reported having attained at least one pass in the Higher Grade examinations (to match the selection criterion of the 1960–2 leavers' survey). In that cohort study, we approximated the parental-education categories of the other surveys by equating primary education to 15 or younger, secondary education to 16, and advanced education to 17 or older. The cohort survey was not used in our analysis because the Scottish sample size (514) was very much smaller than the size of the 1960–2 school leavers' survey (9,171). One consequence of using this imputation is that interactive effects involving year and parental education could not be fitted in the statistical models as well as the interactive effects of year and class, and so only the latter are included.

Statistical models

Because all the outcomes are dichotomous, we model them by logistic regression. For example, this allows us to investigate the change over time in the proportion of each social class who obtained a Higher-Grade science certificate. We show detailed results by means of estimated proportions attempting or attaining the specified certificate, or entering higher education, in order to allow valid comparison of models for different outcomes. (Comparing logistic regression coefficients for different models is not valid (Mood 2010).) The modelling was done in R using the package 'svyglm'. This allowed design weights and post-stratification weights to be taken into account (Gray, McPherson, and Raffe 1983; Croxford, Iannelli, and Shapira 2007, 7). We include school as a clustering variable in the design for svyglm. Analysis of deviance tables are shown using Type II chi-squared tests, which are the results of dropping each term in turn from the model shown in the table. Where predicted proportions are compared in the text, the standard errors were calculated using the function 'vcov' in the 'survey' package. To avoid excessive complexity of predicted proportions, the graphs show three levels of socio-economic status corresponding to the three grouped levels of class in the models and the modal level of parental education for that class group in that year.

The analysis omits respondents for whom sex or attainment were not known (3% of all respondents to the relevant sweeps of the surveys). Missing information on social class or parental education is included as a category in the corresponding variable.

Analysis

Mid-secondary

Table 1 shows the growth of participation in science at mid-secondary level. In the early 1950s, fewer than one in ten students sat any examination in natural science. That rose to one third in the mid-1970s, and one half in the mid-1980s. The new courses and examinations in Standard Grade pushed it to two thirds in late 1980s, and then the curriculum framework brought taking some kind of natural science assessment close to being universal. Attainment followed, with seven out of ten passing at least one natural science course by the end of the century.

Mathematics was ahead of natural science until the coming of Standard Grade, mainly because of the course in arithmetic which was ended at that point. But the rate of attaining any mathematics pass rose to be greater than a half in the late-1990s. Each of the individual natural sciences also expanded, to around one third. General science played only a small role: at most one in twelve students passed it, although in the 1990s just over one in five sat it (22% in 1990–8).

Table 2 summarises statistical models which relate these mid-secondary changes to sex and socio-economic status. On each criterion, there is clear evidence of change over time (the statistically significant effects of the variable 'year'). There is also clear evidence of average statistical effects of class, parental education, and (except in mathematics) sex. Class and parental education have stronger statistical effects than sex except on biology and physics, in the sense that their chi-squared values show that they explain a greater proportion of the total variation: for example, the value for sex in relation to passing at least one science (column 2) is 102, much less than the corresponding values for class (2,392) and parental education (2,738). There is also clear evidence that all these effects change over time (the interactive effects 'year:sex', 'year:class', and 'year:parental education' are all statistically significant). For all natural sciences taken together (the first two columns), there is further evidence that the changes in the sex difference over time varied by parental education (final row). The same is true of general science, but otherwise there is no evidence of such a three-way interactive effect.

Figures 1 and Figure 2 illustrate the patterns of change to which these summary results correspond. By 1998, each SES group and both sexes had 87% or more sitting at least one science (not shown). Resulting from that, there were essentially three patterns of change. The first is illustrated by Figure 1 (passing any natural science). The high-SES group moved ahead first, reaching 80% or higher for males in the mid-1970s and for females in the early 1980s. The other SES groups caught up somewhat by the 1990s. Within each SES group, by the late-1990s the sex difference had vanished or (at low SES) reversed. The pattern for passing mathematics was similar (not shown).

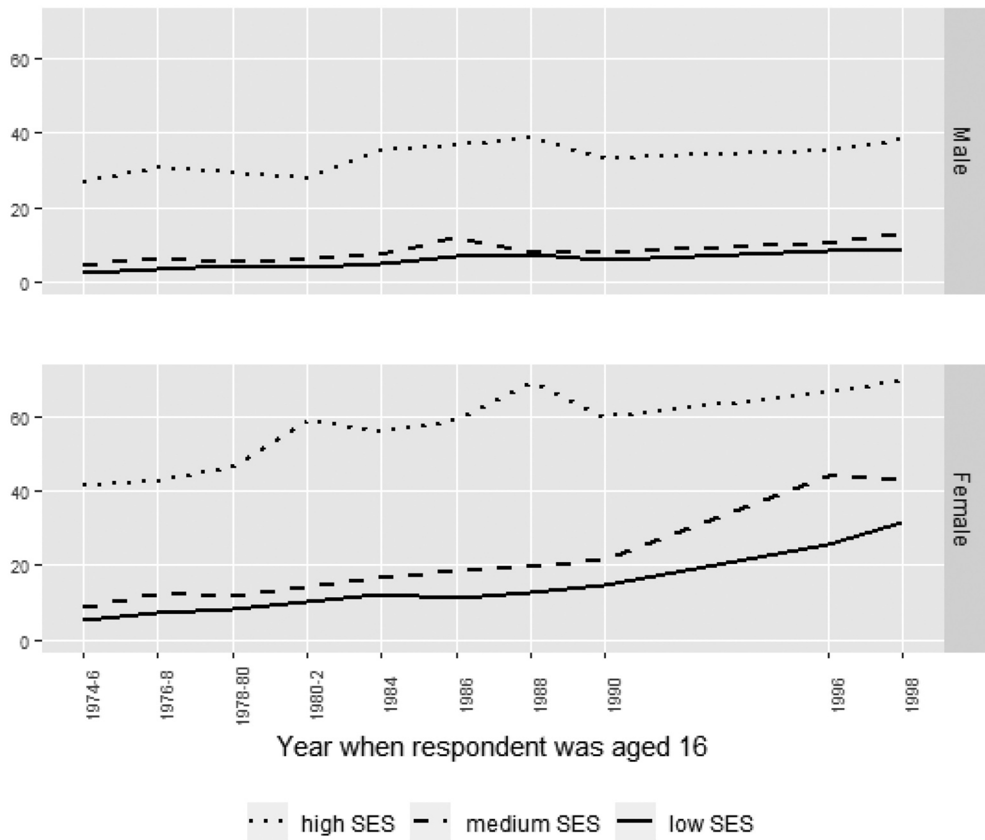

Figure 2. Predicted percentages passing biology at mid-secondary level, by sex, socio-economic status and year. *Source: predicted values from Model 3 in* Table 2.

The second pattern of change is illustrated for biology in Figure 2. Here, the SES gap, though narrowing for females, remained wide, and the sex difference widened or did not change. The odds ratio between high-SES and low-SES female students was 14 in 1976 and 5.0 in 1998. For males, at lower overall proportions, it was 12 in 1976 and 6.2 in 1998. The female preponderance widened: at high SES, the odds ratio rose from 2.0 to 3.8; at medium SES, it rose from 2.4 to 5.1; at low SES, it rose from 1.7 to 4.8. The trajectories of SES difference for chemistry were similar to those for biology, but with the sex difference vanishing by the mid-1980s. The trajectory for physics was, with respect to sex, approximately the mirror image of that for biology.

For each science at the end of the century, the SES difference was at least as great as the sex difference. For example, in Figure 2 (biology), the high-SES lines for the sexes are closer together in 1998 (female-to-male odds ratio of 3.8) than the low-SES line is to the high-SES line for each sex (odds ratios of 5.0 for females and 6.2 for males). The analogous odds ratios for chemistry were 1.1 (male to female), 9.7 (female) and 12 (male). For physics they were 3.5 (male to female), 8.7 (female) and 12 (male).

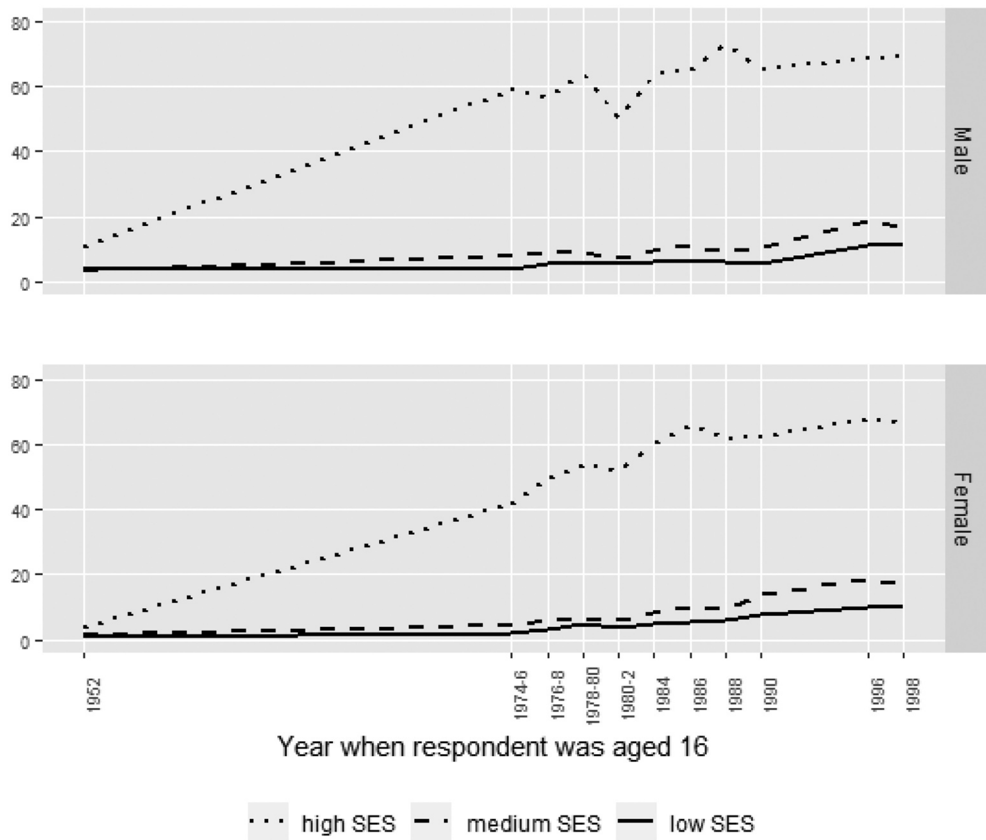

Figure 3. Predicted percentages passing any natural science at Higher grade level, by sex, socio-economic status and year. *Source: predicted values from Model 2 in* Table 4.

The third pattern is found only for general science, where the rate was higher for low-SES than for the other groups. In 1998 at low-SES, 8–9% passed general science, among both males and females. At high-SES, the proportion was only 1–2%.

Thus the main impact of the curriculum framework in the 1990s was achieved through the long-established specific sciences. Scientific literacy was widened, but it still was missed by around one third to one half of low-SES or medium-SES students who did not pass any science courses. Although that pattern was similar for females and males, it was nevertheless differentiated, biology continuing to be dominant for girls and physics for boys.

Senior secondary

The changes at mid-secondary level were extended in more limited ways to the senior stages. Table 3 shows that the proportion of students who passed at least one natural science at Higher Grade rose from 4% in 1952, through one in ten in the 1970s to one in four by the century's end. The trajectory for mathematics was similar. The separate natural sciences each reached about 15% of the age group by the late-1990s. Thus

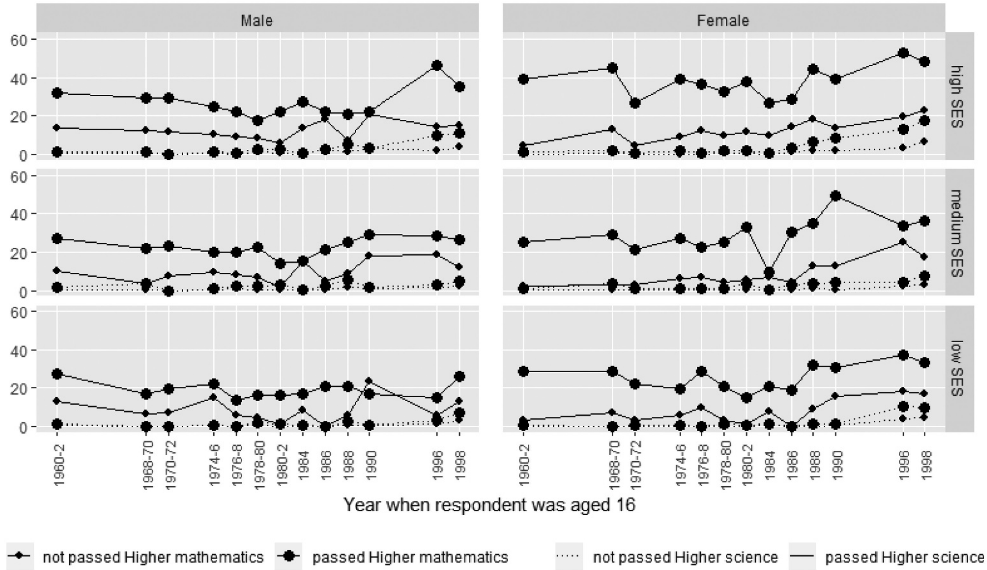

Figure 4. Predicted percentages entering degree courses in pure science, by sex, socio-economic status, and scientific and mathematical attainment, among people who had mean attainment among those who passed at least 1 higher grade at school. *Source: predictions from Model 1 in* Table 7.

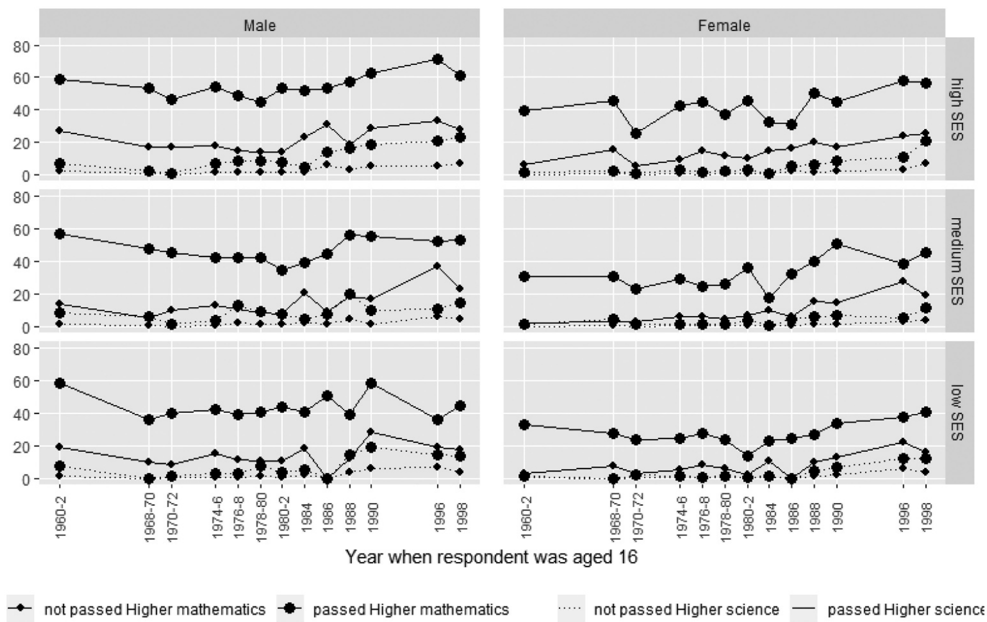

Figure 5. Predicted percentages entering degree courses in science or technology, by sex, socio-economic status, and scientific and mathematical attainment, among people who had mean attainment among those who passed at least 1 higher grade at school. *Source: predictions from Model 5 in* Table 7.

Table 3. Natural science and mathematics at Higher level.

% of sample	Sat any natural science[1]	Passed at least one science[2]	Passed biology	Passed chemistry	Passed physics	Passed mathematics
Year when respondent was aged 16[1]						
1952	4	4	-	-	-	5
1974–6	15	10	3	7	7	9
1976–8	17	13	4	9	8	12
1978–80	19	14	5	9	8	13
1980–2	18	12	5	8	7	12
1984	24	16	7	11	9	14
1986	24	17	8	11	10	16
1988	24	19	10	11	11	17
1990	28	22	12	13	12	19
1996	35	26	15	14	14	26
1998	35	27	15	14	15	27

Percentages weighted; for sample sizes, see Table 1.
[1] *For explanation of which surveys are used here, see Methods section.*
[2] *Not including mathematics.*

scientific participation at an advanced level became quite common. Not shown in the table is that this was achieved largely through the growth of staying on in school beyond age 16. Amongst those who stayed on, the proportion passing at least one natural science at Higher was about one third throughout the half century, similar to the analogous proportion for mathematics.

The changes in the social distribution of science at this Higher Grade level were similar to those at mid-secondary level, but at lower overall levels (Table 4). Again, there is change over time in the effects of sex and of SES (as shown by the statistically significant effects 'year:sex', 'year:class', and 'year:parental education'), illustrated in

Table 4. Binomial logistic models of natural science at Higher grade, by year, sex, class and parental education: Type II chi-squared tests.

		Sat any science[3]	Passed at least one science[3]	Passed biology	Passed chemistry	Passed physics	Passed mathematics
Term in model (: is interative effect)	Degreees of freedom[1]	1	2	3	4	5	6
Year	10, 9	1,670**	1,806**	844**	108**	65**	1,651**
Sex	1	97**	144**	518**	336**	1,697**	125**
Class[2]	2	2,547**	2,030**	894**	1,821**	1,470**	1,963**
Parental education	4	3,177**	3,158**	1,513**	2,364**	2,317**	3,069**
Sex:class	2	23**	10**	5(*)	7*	2	9*
Sex:parental education	4	61**	44**	8(*)	7	12*	57**
Class:parental education	8	78**	73**	40**	67**	53**	54**
Year:sex	10, 9	148**	172**	46**	64**	50**	151**
Year:class	20, 18	34*	48**	39**	33*	39**	52**
Year:parental education	40, 36	967**	946**	120**	88**	118**	1,123**
Sex.year.class	20, 18	12	12	16	13	13	13
Sex.year.parental education	40, 36	256**	230**	39	27	31	300**

[1] *Number of years (as shown in Table 1): 11 for columns 1, 2 and 6, 10 for columns 3, 4 and 5.*
[2] *Class is in three groups: I,II; III; IV,V,other.*
[3] *Not including mathematics.*
The table shows the type-II tests associated with each term.
*Key for statistical significance levels: ** p < 0.01; * 0.01 < p < 0.05; (*) 0.05 < p < 0.10.*

Figure 3 which shows passing any science at Higher. Most of the overall increase was at high-SES, which reached around two thirds for males and females, whereas the other two SES groups remained at less than one third of that. The sex difference vanished in each SES group. The pattern for mathematics was similar (not shown).

As at mid-secondary level, the trajectory in natural science varied by subject, and, at the end of the century, the sex difference was much less than the SES difference. In biology, the proportion of female students who attained a Higher pass grew more than the proportion of males: between 1976 and 1998, the rate rose from 21% to 48% for females, and from 18% to 27% for males. But the trends in the SES gaps were similar: the odds ratio of high-to-low SES went from 26 to 11 for females, and from 22 to 12 for males. Thus the SES gap was far greater than the sex gap, which had a female-to-male odds ratio (at high SES) of 2.5 in 1998. In physics, the proportion passing remained quite stable at just over one half for high-SES males, and at around 30% for high-SES females. The high-to-low-SES odds ratio fell from 35 to 14 among males, and from 30 to 13 among females. The male-to-female odds ratio in 1998 (at high SES) was 3.1. In chemistry, the SES odds ratios fell from 32 to 16 among males, and from 47 to 17 among females, while the male-to-female odds ratio in 1998 was 1.2

Thus for high-SES males and females, quite advanced levels of science became the norm, though with the persisting difference between biology and physics. This advanced level of science remained uncommon at medium and low SES. So, in the late-1990s, the major divide in science at this level was not sex but SES.

Entry to science in higher education

Having thus established that access to science education in secondary school increased, and also broadened socially, we now investigate whether that led to any similar processes in school leavers' entry to the study of science and technology in higher education. Table 5 shows trends for pure science, for technology, and – as a point of comparision – for all disciplines in higher education, both for degree-level study and for any higher education. In the first phase of higher-education expansion (1960s to late-1970s), school leavers' entry to science and technology (column 4) expanded more rapidly than their entry to higher education as a whole (column 6), doubling from 4% in 1952 to 8% in 1978–80 while higher education expanded from 12% to 14%. The expansion continued from the mid-1980s to the end of the century, but at similar rates for science and technology (12% to 19%) and for higher education generally (23% to 38%). The patterns of expansion for degree-level courses were similar to these – science and technology ahead of the general expansion up to the late-1970s, and in line with it in the later period.

In assessing how this relates to the expansion of science education in schools, it is enough to consider attainment in the senior secondary years, because almost the only route to Higher-Grade courses was through the expanding mid-secondary science. From 1976, fewer than 1% of survey respondents without mid-secondary science passed Higher science, and the conversion rate from mid-secondary science to Higher science was quite stable: the proportion of people with an award in mid-secondary science who passed a Higher science was 45% in 1976, 52% in 1990, and 40% in 1998. That is, the rise in Higher science (as seen in Table 3 above) was achieved mainly by means of the rise in mid-secondary science, not by any systematic rise in the proportion of people with mid-

Table 5. Percentage entering science and technology in higher education, 1952–98.

	Degree-level higher education			All higher education		
Percentage *Year when respondent was aged 16*[1]	Science, not technology 1	Technology 2	All disciplines 3	Science, not technology 4	Technology 5	All disciplines 6
1952	1	1	6	3	1	12
1974–6	3	1	8	4	2	13
1976–8	3	2	9	4	3	14
1978–80	3	2	10	5	3	14
1980–2	3	2	9	5	3	15
1984	4	2	12	6	3	19
1986	5	2	14	8	4	23
1988	5	3	19	8	5	28
1990	7	4	23	10	5	33
1996	11	4	29	13	6	39
1998	11	4	30	13	6	38

Percentages weighted; for sample sizes, see Table 1.

[1] *For explanation of which surveys are used here, see Methods section.*

secondary science who proceeded to pass Higher science. Consequently, the relationship between school science and entry to higher-education science can be captured by data on people who passed at least one Higher Grade, shown in Table 6 for the series 1960–2 to 1998. For degree-level courses, there was hardly any change in the rate of entry to pure science up to the mid-1980s, after which the rate rose by about a half (column 1: 14% to 20%). This trajectory from the early 1960s to the end of the century was similar to that for degree courses in all disciplines taken together (column 3). The technology rate, in contrast, rose by much less. A similar pattern is seen for degree and sub-degree levels taken together. Thus from the 1960s to the mid-1980s, pure science, like higher education as a whole, took a constant share of the rising proportion of school leavers who had passed one or more Highers. Thereafter, pure science (and higher education as a whole) took a gently rising share.

These gradual changes conceal striking differences in the changes with respect to sex (again for school leavers with at least one award in any Higher Grade). Whether for degree level or all higher education, the trajectory in the male rate of entry to pure science was u-shaped, falling to 1980–2 and then rising again. For females, by contrast, there was steady growth from less than half the male rate in 1960–2 to equality in 1998. This radical shift in the sex ratio of entrants to pure science was seen at each level of social class. As a result, between 1960–2 and 1998, the percentage of entrants to degree-level pure science who were female rose from 33% to 53% in class I&II, 21% to 57% in class III, and 26% to 49% in class IV,V and other.

But the female rate of entry to technology at any level of higher education remained extremely low: it was about 1–2% until the mid-1980s, and then rose to 4% in the late 1990s. The male rate rose gently, from around 15% before 1980 to around 20% after the mid-1980s. In principle, then, the rising share which pure science took of people with one or more Highers (as seen in Table 6) could be due to the rise in female participation, and, similarly, the reason why technology did not rise similary could be due to persistently low female participation.

These speculations are tested in Table 7 and illustrated in Figures 4 and Figures 5. The models control for general attainment at Higher, and also for whether the leaver has an award in Higher mathematics and a Higher science (the trends in which were shown in Table 3, and which, for people with at least one Higher, may be derived using that table and the first column of Table 6). They also control for sex, social class, and parental education. For entry to pure science (whether at degree level or more generally), the strongest statistical effects are from attainment in mathematics or in science, or in the change in these effects over time. For example, in entry to degree-level pure science, the chi-squared value for 'science attainment' is 9282, greater than for any other term. There are also statistically significant interactive effects of these with sex and class, especially for entry to degree-level courses. For example, in entry to degree-level pure science, the interactive effect 'sex:science attainment' is a statistically significant 24.9, and for 'class:science attainment' is a statistically significant 503.3. For entry to technology the strongest statistical effect (after the change over time) is sex, in the first row of the table, and these sex differences change over time (the 'year:sex' terms). In other respects, however, the broad patterns of effect for technology are similar to those for science, including the interactive effects with class.

Table 6. Percentage entering science and technology in higher education, among people who had passed at least 1 Higher grade at school, 1962–98.

	Proportion of all school leavers reaching this level[2]	Degree-level higher education			All higher education			Sample size for all but first column (=100%)
Percentage		Science, not technology	Technology	All	disciplines	Science, not		technology
Technology	All disciplines							
Year when respondent was aged 16[1]		1	2	3	4	5	6	
1960–2	15	14	7	37	14	8	42	9,171
1968–70	25	13	5	37	15	7	49	2,482
1970–2	27	11	4	34	13	7	42	2,779
1974–6	27	13	6	37	16	8	53	7,207
1976–8	26	13	7	36	16	10	53	1,775
1978–80	27	12	7	35	16	9	48	6,795
1980–2	27	12	7	34	16	11	48	2,531
1984	32	12	7	38	17	10	55	1,760
1986	33	14	7	42	21	11	64	1,918
1988	37	14	9	51	19	12	69	1,847
1990	41	16	10	55	22	12	74	1,582
1996	50	20	8	56	24	10	69	1,549
1998	52	20	8	56	23	10	68	3,163

Percentages weighted; sample sizes unweighted.
[1] *For explanation of which surveys are used here, see Methods section.*
[2] *Proportion of school leavers passing at least one Higher. Sources*: Scottish Education Department (1971, 28, 1973, 29); Gray, McPherson, and Raffe (1983, 205); *surveys described in Methods section.*

Table 7. Binomial logistic models of entry to science and technology in higher education, among people who had passed at least 1 Higher grade at school, by sex, class, parental education, general attainment, and scientific and mathematical attainment, 1962–98 Type II chi-squared tests.

Term in model (: is interative effect)	Degrees of free-dom	Science, not technology (degree)	Science, not technology (any higher education)	Technology (degree)	Technology (any higher education)	Science or technology (degree)	Science or technology (any higher education)
		1	2	3	4	5	6
Sex	1	40.9**	171.5**	17,028.3**	2650.3**	583.8**	570**
Class	2	354.6**	7.5*	1560.7**	3.1	226.8**	2.2
Parental education	4	13.2*	14.2**	5.5	2.4	9.9**	9.1(*)
General attainment	1	772.2**	213.8**	0	141.5**	578.4**	18.9**
Sex:class	2	6.3*	5.7(*)	107.7**	0.4	2.9	4.7(*)
Sex:parental education	4	1.4	3	4.8	9.4	1.2	3.6
Sex:general attainment	1	5.9*	85.8**	31.1**	37.4**	4.2**	0
Class:parental education	8	12	3.8	23.7**	25.9**	13.6(*)	9
Class:general attainment	2	3.8	1.1	8.3*	10.3**	13.5**	5.5(*)
Parental education: general attainment	4	5.8	5.7	3.9	2.3	9.9**	5.2
Sex:class: parental education	8	7.8	10.7	4.9	8	6.6	4.8
Sex:class: general attainment	2	4.3	0.3	0.4	0.6	7.6**	5.3(*)
Sex:parental education: general attainment	4	7	6.1	11.9*	6.1	4.7	9.9*
Class:parental education: general attainment	8	3.7	7.1	7.4	6.5	7.1	12.5
Sex:class: parental education: general attainment	8	13.8(*)	16.6*	4.6	6.4	9.2	4.6
Year	12	7536.7**	430.2**	24,241.4**	6582.9**	5064.9**	581.2**
Year:sex	12	75.1**	32.6**	5905.7**	984.5**	30.2**	33.8**
Year:class	24	1695.6**	59.5**	4522.2**	78.6**	2458.3**	47.7**
Year:general attainment	12	164.3**	185.3**	39.7**	9.8	181**	219**
Year:sex:class	24	30.3	24.9	3556.4**	29.3	33.2(*)	19.1
Year:sex: general attainment	12	15.8	17.3	22.1*	20.7(*)	9.4	9.5
Year:class: general attainment	24	15.8	15.9	22.6	20.2	19.5	18.9
Science attainment	1	9282.2**	2228.2**	4230.5**	1386.4**	3917.5**	3165.6**
Mathematics attainment	1	790.8**	518.6**	3146.3**	729.2**	1632.8**	1391.4**

(*Continued*)

Table 7. (Continued).

Term in model (: is interative effect)	Degrees of freedom	Science, not technology (degree)	Science, not technology (any higher education)	Technology (degree)	Technology (any higher education)	Science or technology (degree)	Science or technology (any higher education)
Year:science attainment	12	5957.5**	170.6**	3983.1**	434.1**	1246.4**	145.5**
Year: mathematics attainment	12	525.2**	43.9**	2268.6**	22.3**	401.6**	32.3**
Sex:science attainment	1	24.9**	0.2	22**	52**	11.1	3.2(*)
Sex: mathematics attainment	1	29.1**	7.3**	25.5**	18.3**	0.2	24.3**
Class:science attainment	2	503.3*	0.1	164.8**	2.2	209**	1.9
Class: mathematics attainment	2	165.6**	0.2	838.6**	4.9(*)	169.2**	0.8
Parental education: science attainment	4	4.4	5.4	3.3	2.6	7.1	5.3
Parental education: mathematics attainment	4	5.7	7.9(*)	0.7	2.5	4.3	2.2
Year:sex: science attainment	12	621**	18.4(*)	642.7**	505.5**	17.3	14.1
Year:sex: mathematics attainment	12	16.7	23.4*	663.6**	21.2**	12.5	25.6**
Year:class: science attainment	24	1409.6**	33(*)	1475.1**	19.9	1293.3**	25.7
Year:class: mathematics attainment	24	957**	28.9	1620**	23.8	1042.7**	34.7(*)

*Key for statistical significance levels: ** p < 0.01; * 0.01 < p < 0.05; (*) 0.05 < p < 0.10.*

Figure 4 shows the predicted entry rates to degree courses in pure science, with respect to sex, socio-economic status and whether or not awards are held in either Higher mathematics or Higher science. The predictions are at mean overall attainment among this group of students (which was equivalent to about four Higher Grades in each year). The effect of holding an award in science is shown by the difference between the solid and dotted lines, and the effect of mathematics by the difference between the large and small circles on the lines. Fewer than one in ten of these leavers entered science without a science award, and fewer than one in five did so without mathematics. So the solid lines with large circles are the most interesting, being the rates of entry for people with both Higher mathematics and Higher science. We refer to these as scientifically qualified entrants.

Consider first the scientifically qualified female entrants from high-SES familes (the top-right graph). These showed a gentle though fluctuating rate of entry over time, from 39% in 1960–2 to 50% in 1996–98 (standard error of difference 6; p = 0.06). There was a similar gentle rise for high-SES males in the top-left graph (32% to 41%; s.e. 4; p = 0.05). There was weak evidence of a female advantage in the 1990s, the average difference in 1996–98 being 10 points (s.e. 6; p = 0.09).

At medium SES, females perhaps showed a modest increase over time (25% to 35%; s. e. = 6; p = 0.13), while the rate for males was stable at 27%. So there was no evidence of a sex difference (p = 0.69 for 1960–2; p = 0.16 for 1996–98). At low SES, the female rate probably did not change (29% in 1960–2, 35% in 1996–98; s.e. of difference 7; p = 0.33). The estimates of the male rate fell (27% to 21%), and so, in 1996–98, there was evidence that the male rate was 15 points lower than the female rate (s.e. 7; p = 0.04).

The general absence of firm evidence of sex differences suggests that the main factor influencing the relative growth of female entry was changes in the sex ratio in gaining Higher science and mathematics among students who had gained at least one Higher at school, not to any change in the sex ratio of entry between scientifically qualified females and males. These patterns were similar for entry to pure science at any level of higher education, but for technology males were far ahead of females at all levels of SES, and regardless of whether the student had an award in Higher science or mathematics.

If we then combine pure science and technology, we get the patterns (for degree level) shown in Figure 5. In contrast to Figure 4 (pure science), males are now generally ahead. The rates for high-SES females did move firmly up (39% to 57%; s.e. 6; p = 0.002), while those for high-SES males rose more gently (58% to 66%; s.e. 4; p = 0.08). But, despite this, males were consistently higher (1960–2: s.e. 5; p < 0.01; 1996–98: s.e. 5; p = 0.08). Mostly the same was true at medium and low SES, though there was no evidence of a sex difference for low-SES in 1996–98.

In summary, scientifically qualified women from high-SES families never, at any time in this period, had a rate of entry to pure science that was behind that of similar men, and these women may have had a higher rate in the 1990s. Scientifically qualified women in other SES groups were never behind their male counterparts. But scientifically qualified males always had far higher rates of entry to technology than similar females, and so, in the scientifically qualified group of school leavers, the overall male rate of entry to science and technology combined was consistently ahead of the female rate.

Conclusion

The main strength of this analysis of school students' participation in scientific education is the length of the time series, covering the whole of the second half of the twentieth century. The surveys allow an analysis of students' movement through scientific study at mid-secondary level, to senior-secondary level, and then into science and technology in higher education. The main weakness of the data is that there is no prior information about intelligence or aptitude for science that would allow us to distinguish between the effects of schools and the effects of other influences. Nor is there any series of questions about attitudes to science. Thus we have not been able to draw any causal inferences, and the analysis is best thought of as a description of the trends in the social differentiation of scientific study during a period of very extensive social and educational change.

Participation in science grew following the shift to comprehensive education, both during the compulsory school stages and later. By the end of the century, one quarter of students attained at least one Higher Grade certificate in a natural science. This then was almost the entire explanation in a statistical sense of the expansion of science in higher education. By the late-1990s, almost as high a proportion of the age group was entering some kind of science or technology in higher education (19% in Table 5) as had passed any mid-secondary science in the mid-1970s (22% in Table 1), and the proportion entering scientific or technological degree programmes was three times the level passing any mid-secondary science in the early 1950s. This expansion was achieved as a result of the expansion of science in secondary school, because the rate of entry to higher education science by people who had scientific qualifications from school barely changed (Figure 4).

Sex differences shrank at both mid-secondary level and at Higher Grade in mathematics and in chemistry, and in all natural sciences combined. Female students continued to dominate biology, and male students physics, with little sign of these differences weakening. The most striking sources of difference at school level were in relation to socio-economic status. These differences were ended altogether in the move to universal participation at mid-secondary level in taking courses in natural science, and were much reduced in passing such courses. In all other respects, the socio-economic differences at the end of the century were still wide, even though narrower than between the 1950s and the late-1970s. The socio-economic differences were greater than the sex differences at Higher Grade.

Sex and socio-economic differences in entry to pure science at higher education were a product of the analogous differences at school (a finding similar to that of Jacob et al. 2020). Female participation rose faster than male, because female participation in science at school also rose faster. From the early 1960s onwards, scientifically qualified female students from all socio-economic groups were never behind similar male students in their rate of entry to pure science in higher education, and by the end of the century women from high-SES groups were somewhat ahead of similar men. That conclusion was in stark contrast to the very low rate of entry to technological courses by scientifically qualified women of all social groups.

This conclusion about the importance of reforms to the secondary-school curriculum in changing the social distribution of scientific study is similar to that by, for example, Ayalon and Livneh (2013), Charles and Bradley (2002) and Jacob et al. (2020), but has been reached, not by comparative research as in these authors' work, but by following a single country over a long period of time The present research thus adds a new chronological dimension to these authors' conclusions.

Our data have offered evidence only in relation to opportunity, and cannot say anything directly about the other two themes in the debate about scientific education which we discussed earlier – the economy, and citizenship. But our conclusions do allow us to make two final, tentative comments about these. On the economy, the sheer scale of the increasing participation that we traced suggests that there is no straightforward educational response to economic difficulties. Policy makers have repeatedly sought to expand scientific education in response to the kinds of economic argument which have been made since the 1950s (and earlier). We have seen that the resulting expansion of scientific education was large. So if science still has more to contribute to economic activity, then it will have to be by means other than educational reform.

On citizenship, on the other hand, it does seem likely that the expansion of participation will have had some effect. The extension of scientific literacy to two thirds of the age group, the expansion of science in higher education, and the growing participation by women in pure science were all due to reforms which extended scientific opportunities to an unprecedented range of students in mid-secondary school. Many psychologists have pointed out that, during the twentieth century, there was a rise in the understanding of reason and evidence that was expected of school students (Flynn 2007: 42; Pinker 2011: 791–3; Ritchie 2015, 94–9). Pinker argues that what Flynn called 'scientific spectacles' strengthened citizens' capacity to 'frame ideas in abstract, universal terms'. If this moral improvement has indeed been the result of growing access to scientific education then the detailed ways in which that has come about have been illustrated by the data which we have presented here.

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No potential conflict of interest was reported by the author(s).

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